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Multi-Source Energy Optimization in BLDC Motor Electric Vehicles Using Intelligent Management Systems

Yash Ladole[1], Pratik Ghutke[2], Ganesh Wakte[3]

[1,2,3]Department of Electrical Engineering
Tulsiramji Gaikwad Patil College of Engineering & Technology,
Nagpur, India,

Abstract
Diesel and gasoline have historically been the two primary fuels used in the automotive industry. However, electric vehicles will eventually be replaced by internal combustion engines. Compared to internal combustion engines, electric vehicles use less gasoline, but their range is limited by the lack of charging stations. The range of electric vehicles using regenerative braking can be increased by charging the batteries whereas the vehicle is braking. This project shows a simulation of BLDC power control with regenerative braking. Using the Matlab/Simulink tool, this study provides a comprehensive simulation of how a BLDC motor with regenerative braking operates as a machine and a generator. A simulation showed that an energy recovery of 0.35 percent was achieved.

Keywords: Electric vehicles, regenerative braking, BLDC motor, inverter, battery etc.

1. INTRODUCTION

Regenerative braking is the greatest choice for further increasing the range of EVs. By adopting regenerative braking, brake energy that would otherwise be lost can be recycled. Vehicles using traditional IC engines are not capable of using regenerative braking. Regenerative braking involves reintroducing battery energy that is lost during braking. With this method, the electric motor produces electricity due to the inertia of the vehicle. In order to charge the battery, batteries act as a load that is electrically coupled to the generator. It has been demonstrated that regenerative braking can increase an electric vehicle's range by 15% to 20%. However, there are certain restrictions, such as the fact that it is not feasible to charge the battery while it is fully charged.

In this case, in an effort to prevent being wasted as heat, the electrical energy that is generated is wasted as heat. As a result, in addition to regenerative braking systems, EVs also need mechanical brakes. International regulations state that mechanical brakes are a must for every vehicle when considering an emergency situation and the security of the vehicle and its occupants. EVs can do both mechanical and regenerative braking with a single pedal, according to studies. If the driver continues to depress the brake pedal, mechanical brakes will be applied after the initial stage of regenerative braking. The transition from mechanical to regenerative braking is seamless, so the driver won't notice it. EVs can reach comparable braking performance to internal combustion engines.

2. METHODOLOGY

A. BLDC Motor with Hall Effect Sensors

They call it a "brushless DC motors." A brushless DC motor was an electric motor which is supplied by a DC voltage source and, in contrast to traditional DC motors, uses an electronic gearbox in place of brushes. It is the most desired electric drive due to its high efficiency, great power saving capability, long lifespan, and small size. The motor rotor is located using the hall effect sensors. For BLDC motors to operate as switching devices, the rotor position needs to be known. To determine the position between their rotors, BLDC motors can be utilized with or without sensors. The transition of the back EMF generated in phases through a single point is recognized in the case in sensor-less position determination. As a result, the order of switching is determined. The stator is equipped with Hall effect sensors to monitor the rotor's position. For a two-phase BLDC motor, three hall effect detectors are more than sufficient. These sensors are positioned in the rotor at 60° or 120° angles to find the rotor of a BLDC motor, while 120° hall sensor are used.

The component that makes the BLDC motor possible is the inverter. It makes use of IGBT or MOSFET switches. The on-state loss of voltage is higher with MOSFETs. Every stator phase uses two IGBT switches. the BLDC motor's three-phase, three-phase inverter circuit. Bi-directional converters that convert DC to DC are used to obtain the required voltage level because energy storage requires a voltage higher than the nominal voltage of the battery. During regenerative braking, a boost converter raises the DC voltage of the BLDC motor.

B. Inverter, Bi-Directional DC-DC Converter, and Regenerative Braking

Electric motors go into generator mode when the driver applies the brakes. The drive train may allow the wheels to transfer kinetic energy to a generator. A fraction of all kinetic energy is transformed into electrical energy by the generator's rotation. A high voltage batteries holds this power in reserve. An electric motor's energy output results in braking torque, that slows down what is moving object. For example, the friction brake have to be used in order to preserve necessary deceleration because the electric motor is incapable of producing enough braking torque just before the auto stops moving at a slow speed. The frictional brake's braking torque is continuously adjusted to the freshly generated braking torque during the torque blending process. Generally speaking, the friction brake only slows down the car when complete braking is applied, there are erratic driving conditions, and wheel-specific actions are needed.

Bidirectional DC-DC converters have been the subject of extensive research and development in recent years for a variety of uses, including UPS systems, electric cars, and battery chargers. For hybrid electric vehicles, DC-DC converters that are bidirectional are a crucial part of the traction systems. For electric automobiles (EVs), a DC motor drive operated via a bidirectional DC to DC converter may effectively manage both motor and brake regeneration functions, greatly boosting the overall efficiency of the drive system. Two distinct DC voltage levels can be converted in both directions using a bi-directional DC-DC converter, which can also change the direction of power flow.

There are two primary goals that the DC-DC converter must achieve. The voltage of the battery must first be equal with the nominal motor power in order to ensure that the power used for driving satisfies the requirements. Controlling the power flow in both constant and transient phases is the second. In electric car batteries that use converter-driven motor drives, the input terminals at the inverter are frequently directly powered by low voltage battery power. However, these inverter feeders have a detrimental effect on the motor's efficiency during driving and are unable to regulate the regenerative braking system. In actuality, an appropriate motor brake current regulates and helps to replenish the vehicle's battery in this way. The DC link in a battery-fed AC drive motor for EV applications can be connected to a bidirectional DC- DC converter to solve the previously described issues. A DC-DC converter is used to increase the battery voltage, allowing the motor to operate efficiently throughout the vehicle's speed range. Additionally, the bidirectional construction of the DCDC converter allows for the regulation of the motor braking and electricity flow reversal.

C. PID Controller and Inverter

For ground vehicles, batteries serve as the primary energy storage device. Due to their many benefits, such as their near-zero emission levels, ensured load balancing, good dynamic performance, and capacity to recover energy during braking, battery-fed electric drives have become widely employed. Connecting the accumulation tank (battery) to the motor driving system's intermediate circuit requires a gadget that can transfer power in both directions. Battery-fed electric vehicles (BEVs) have three different modes of operation: braking (regeneration), baseline (stationary), as well as accelerating. While power is delivered from the source of power to the motor within the normal and accelerated modes, the motor's movement energy is transformed into electrical energy as well as sent back to the battery in recuperation or brake modes. Proportional-Integral-Derivative Controller is its full name. These three mathematical elements determine the speed of the error and make the necessary adjustments. In proportional control, the discrepancy between the set values then the process parameter (error) is computed, and the necessary adjustments are made in accordance to the reference speed. The integral equation continuously modifies the offset between the procedure variables and fixed locations (reference speed). Control adjustments are made while the derivative equation constantly monitors the process variable's (error signal's) rate of change.

D. Simulation

To effectively illustrate how the motor capacity which battery current affect the regenerating energy, a vehicle simulator is first constructed using MATLAB/Simulink which is shown in Figure 1. In order to understand the root cause of the occurrence, this paper creates a straightforward model that combines the motor differential equation with the vehicle differential equation. The model assumes that that the car has a single motor coupled to a gear that has programmed ratio, as well as the ideal situation, which eliminates bobbing, pitching, as well as rolling motions. By giving the speed controller a speed reference and a torque measurement, the demand for power and torque are calculated as output with the vehicle model, wherever the output torque equals the reference.

3. Project Description

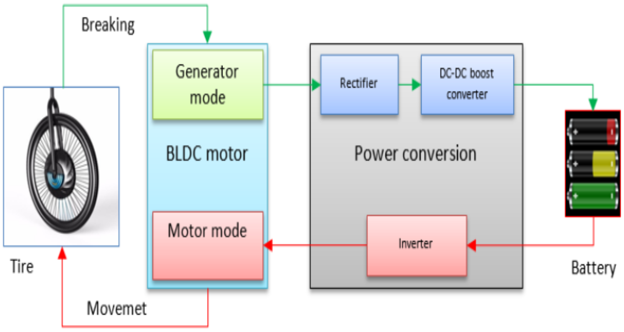

Figure 1. System block diagram

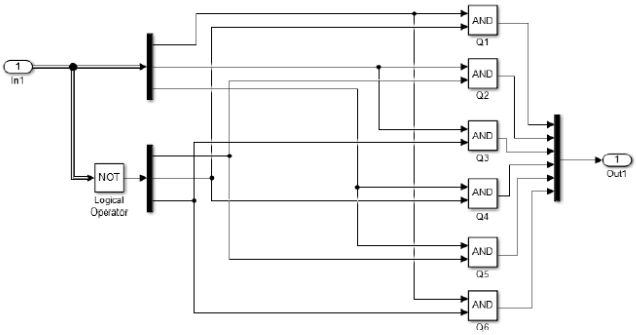

Figure 2. BLDC motor logic circuit for switching

The above figure depicts the standard RBS setup with a BLDC motor. The hub motor used in the in-wheel drive system under investigation in this study is connected to the wheel directly, without the need for a gearbox mechanism. The vehicle moves with the required acceleration and velocity when in propulsion mode because the engine is powering the wheel in grip mode. Upon receiving the brake signal transmitted by the accelerator sensor, the controller mode is switched to regenerative braking, which uses a rectifier with DC-DC converter to charge the battery while the motor stays in generator manner and the rotational force stored in the wheels is transformed into electrical energy.

A straightforward yet efficient method of BLDC motor-based BEV regeneration is suggested. During regenerative braking, the BLDC motor was allowed to spin with its own inertia. The battery was charged with the help of a boost converter, which increased its put back EMF value to the highest level allowed by the battery voltage. This method resulted in the energy usage of the BLDC motor. Regenerative braking is an option for all electric vehicles. A significant amount of lost energy is expected to be reclaimed as the number about electric vehicles with the roadways increases.

4. MATERIAL

A. BLDC motor and driver

There are BLDC motors as well as DC motors. They do not, however, function in the same manner as conventional DC motors. A conventional DC motor consists of two parts: a rotor plus a stator. The stator is the fixed part of the field windings. In this case, a fixed field magnitude stationary magnetic is produced. The part of a vehicle that revolves is called the rotor. Here, the rotation is maintained by the commutation, which is the change within current direction, that occurs when the brushes come into contact with the collector. A constant DC voltage is applied to the stator and rotor.

Fixed magnets make constitute the rotor, a moving part of BLDC motors (Rakesh & Narasimham, 2012). There isn't a brush or collector in the structure. The stator is composed of silicon steel sheets and phase windings. The phase windings are switched one after the other to generate the stator's rotating magnetic field. Motor movement is guaranteed by the connection among the rotating device and the stator.

BLDC motors' both inside and outside rotors can be divided into two categories. The use of electric vehicles determines both inner and outer choices. The selection of internal and external components for electric vehicles is based on their intended purpose. They can be classified into two categories sinusoidal or trapezoidal based on the back EMF waveform.

Because BLDC motors are designed without a brush, so is no loss of heat through friction. Compared to conventional DC motors, they are quieter and more robust. However, the cost is greater. Additionally, control systems are increasingly intricate. To simulate this investigation, a three separate phases trapezoidal BLDC drive is used.

Hall effect sensors are used to determine the locations of BLDC motors. For BLDC motors to switch, the rotor position needs to be known (Nian et al., 2014). Without or with a sensor, BLDC motors' rotor position can be ascertained (Sindhuja with Ranjitham, 2014). In the setting of sensorless position determination, the transition of the back EMF generated in the phases through the point where nothing happens is recognized. Consequently, the new sequence is selected.

Hall effect detectors are mounted on the stator to detect the rotor's position (Elavarasi & SenthilKumar, 2014). Three hall effect detectors are more than plenty for a triple-phase BLDC motor. These sensors are positioned in the stator at 60° or 120° angles (Karabacak & Uysal, 2017). In this work, the rotor position of the BLDC motor is ascertained using 120° hall sensors.

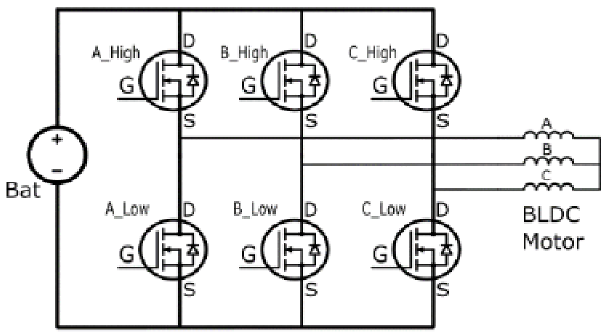

Figure 3 . BLDC motor driver structure

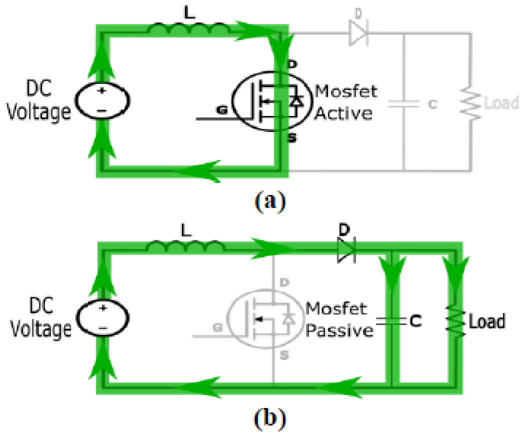

Figure 4. Boost converter (a) MOSFET on (b) MOSFET off

The component that makes it possible to push the BLDC motor is the inverter. Semiconductors make up the switches. Fast switching is made possible by this kind of switch. Two switches are employed for each stator phase. Figure 1 shows the inverter circuit for a three-phase BLDC motor.

The battery is the most important part of electric cars. This guarantees the system's complete energy supply and permits the storage about electrical energy (Suvak & Erşan, 2016). According to Junzhi et al. (2014), there is also where the energy produced during regenerative braking procedures is stored. Energy must be stored in the battery by applying a voltage greater than its voltage (Cano et al., 2018). Booster converters are used in low-voltage systems such as these to raise the voltage required for energy storage.

B. Boost Converter

During regenerative braking, a boost converter is used to increase the DC voltage on the BLDC motor. It is made up of a MOSFET semiconductor switch, a coil, and a diode. Figure 2 displays the boost converter structure's switching points.

The battery cannot be stored with the BLDC motor's reverse electromagnetic fields level throughout the stopping period (Jang et al., 2009; Zhou & Fang, 2013). because the voltage produced is less than the voltage in the battery. The generated voltage must therefore be increased (Bobba & Rajagopal, 2010; Long et al., 2014). However, standard transformers cannot increase the generated voltage because it is not AC. Therefore, a converter from DC to DC boost is employed to raise the voltage.

$$\frac{V_o}{V_i} = \frac{1}{1-D} \qquad (1)$$

where D is the amount of duty cycle during which the switch stays in its position, Vo is the resultant voltage, and Vi is the source voltage.

5. SIMULATION MODEL OF BLDC MOTOR WITH REGENERATIVE BRAKING

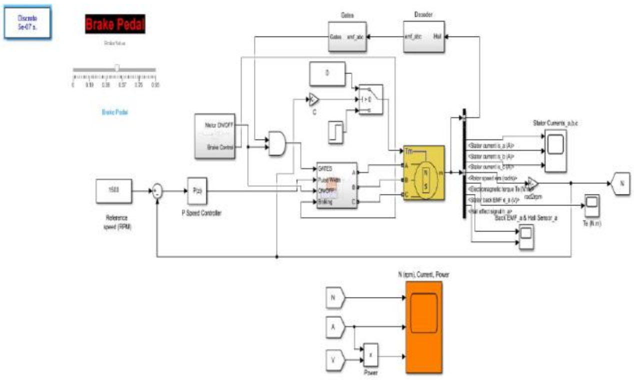

Figure.5. BLDC motor simulation model with regenerative braking

Regenerative braking is one type of energy recovery mechanism used in EVs. The speeding cars simply release their momentum as heat when braking forces are applied, which is pointless. This energy is converted by RBS into mechanical or electrical energy, which powers the vehicle. It increases the vehicle's efficacy and efficiency.

The battery's generator converts kinetic energy into electrical energy in this configuration. The electrical energy kept inside the battery powers the motor that is connected to the driveshaft.
There can be three different types of brakes in this system, depending on how much pressure is applied to the brake pedal.

1) No regenerative energy will be produced when there are no brakes.
2) The battery will only receive the minimum current when there is light braking.
3) Under severe braking circumstances, the full current will be returned to the battery.

6. RESULT

The graph illustrates the battery's current-time graph. In the initial state, the battery to BLDC motor current flowed in one way. The graph was in the positive area, indicating that the battery was using energy. When the brake was applied, the current-time graph shifted from the BLDC motor's voltage to the power source as regenerative braking began to operate. It implied that the BLDC motor's energy was stored in the battery. There, regenerative braking also took place. The back EMF of the BLDC motor was operating both with and without regenerative braking. When the regenerative braking system was done to the BLDC motor, the battery was provided with as a load. Consequently, the posterior EMF curve became narrower along its length axis once the brake was applied. The two graphs show that the recorded back EMF had cycle but phase-phase voltages around 20 V and 40 V, accordingly, as the brake was applied but the deceleration began, and that these voltages decreased over time.

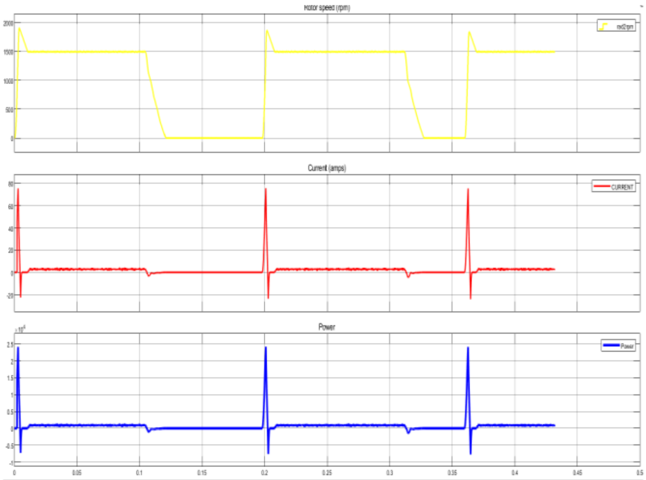

Figure.6. Rotor speed, power (amps), and power graph following the application of regenerative braking.

This result was obtained by simulating a BLDC motor having regenerative braking, with a focus on electric car applications. The simulation uses a battery-operated BLDC with VSI controls to provide braking, acceleration, and deceleration. Whenever braking occurs, the motor shifts to generator mode, which causes the wheel to spin because of its own inertia. At the same time, the DC-DC converter charges the battery and reverses the energy flow.

7. Conclusion

This work provided a straightforward yet efficient technique for power regeneration in BEVs with BLDC motors. The BLDC motor was permitted to rotate using its own inertia while regenerative braking was in effect. With the aid of a boost converter, the battery was fully charged and the resulting back EMF value was raised to the maximum level allowed by the battery voltage. This technique led to the energy consumption of the BLDC motor. Every electric vehicle has regenerative braking. As the number in electrically powered cars on the the road rises, a sizable portion of the electricity wasted will ultimately be recovered.

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